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14. ABSTRACT

The Infrared Sensor Stimulator (IRSS) system will be used to stimulate installed infrared/ultraviolet (IR/UV) electro-optic (EO) sensors undergoing integrated developmental and operational testing. IRSS generates digital IR scenes in real time to provide a realistic portrayal of IR scene radiance as viewed by and IR system under test in a threat engagement scenario. This paper will describe the continuing IRSS development effort including new work completed in the past year. There will be a brief overview of the IRSS subsystems and functions, with emphasis on recent enhancements to its IR modeling capabilities. Specifically, the paper addresses issues involving the integration of three IR models: Spectral In-Band Radiance of Targets and Scenes (SPIRITS), Physically Reasonable IR Signature Model (PRISM), and IR Electro-optical Naval Engagement (IRENE). Also, there will be discussion regarding use of a radiometrically accurate method of employing geospecific material properties in the rendering of background terrain.

15. SUBJECT TERMS

Installed Systems Testing, Infrared Sensors, Scene Simulation, Sensor Fusion, Interoperability, Electronic Combat Test Process, Infrared Scene Projection, Sensor Stimulation

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Joint Navy and Air Force Infrared Sensor Stimulator (IRSS) Program for Installed Systems Test Facilities (ISTFs)

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ABSTRACT

The Office of the Secretary of Defense (OSD), Central Test and Evaluation Investment Program (CTEIP) is tasked to provide a coordinated process for making joint investments in defense test & evaluation (T&E) to offset the challenges presented by declining investments in test assets and increasing test requirements. Under CTEIP sponsorship, the Navy and Air Force are jointly developing three Joint Installed System Test Facility (JISTF) enhancements that are based on dynamic virtual reality simulation technology. The three enhancements are the Infrared Sensor Stimulator (IRSS), Generic Radar Target Generator (GRTG), and Joint Communications Simulator (JCS). The subject of this paper is the IRSS that was first briefed at the 1997GTM&V conference.

The IRSS system will be used to stimulate *installed* Infrared/Ultraviolet (IR/UV) Electro-Optic (EO) sensors undergoing integrated developmental and operational testing. IRSS generates digital infrared scenes in real-time to provide a realistic portrayal of infrared scene radiance as viewed by an IR system under test in a threat engagement scenario. This paper will describe the continuing IRSS development effort including new work completed in the past year. There will be a brief overview of the IRSS subsystems and functions, with emphasis on recent enhancements to its IR modeling capabilities. Specifically, the paper addresses issues involving the integration of three IR models: SPIRITS (Spectral In-Band Radiance of Targets and Scenes), PRISM (Physically Reasonable IR Signature Model) and IRENE (IR Electro-optical Naval Engagement). Also, there will be discussion regarding use of a radiometrically accurate method of employing geo-specific material properties in the rendering of background terrain.

KEYWORDS: Installed Systems Testing, Infrared Sensors, Scene Simulation, Sensor Fusion, Interoperability, Electronic Combat Test Process, Infrared Scene Projection, Sensor Stimulation.

INTRODUCTION

The Infrared Sensor Stimulator (IRSS) is a modular cost-effective system that will be used to generate high fidelity Infrared (IR) scenes for stimulation of *installed* IR Electro-Optic (EO) sensors on aerospace platforms undergoing integrated developmental and operational testing. The IRSS will be capable of stimulating multiple types of sensors such as Forward looking Infrared (FLIR), Missile Warning Systems (MWS), Infrared Search and Track (IRST) and Missile Seekers. It is being developed under the sponsorship of the Office of the Secretary of Defense (OSD) Central Test and Evaluation Program (CTEIP) for use in a Joint Installed Systems Test Facility (JISTF) environment. The IRSS will be capable of satisfying installed sensor system test requirements through dynamic stimulation of IR/EO sensors which are integrated with other avionics processing software and platform sensor systems, (e.g., radar, operational flight programs (OFP)). To be a valid test tool, the spatial, spectral and temporal components of the IRSS computer-generated synthetic scenes must be of sufficient fidelity to produce sensor responses that are indistinguishable from the tested sensor's response to "real-world" conditions. This paper discusses the current capabilities and recent additions to the IRSS.

IRSS OVERVIEW

The IRSS System is an integrated hardware/software system that has been specifically designed to support the design, development, integration, and testing of IR/EO sensor systems. The IRSS will be able to support both performance characterization and integrated sensor testing. The IRSS system generates radiometrically correct scenes in real-time for reactive installed systems testing of a variety of infrared and ultra-violet sensor systems. The generated scenes provide a realistic portrayal of the infrared scene radiance as viewed by the unit under test (UUT) in operational scenarios. Use of commercial-off-the-shelf (COTS) Silicon Graphics (SGI) fast symmetric multiprocessing hardware has minimized cost and development time. During real-time scene simulation, the multiprocessors are used to update polygon vertex locations and compute radiometrically correct floating-point radiance values for each waveband. Scene radiance is calculated on a frame by frame basis accounting for the relevant contributions from the sky, sun, targets, terrain, and atmosphere as a function of the engagement geometry by using existing validated high-fidelity IR models.

The frame output of the IRSS system is configurable to match the characteristics of the sensor system under test. Sensor parameters such as frame size, frame rate, spectral band, number of bands, pixel resolution, and field of view are user configurable. The digital output of the IRSS can be formatted for direct injection into receiver/processor hardware or to drive an infrared projection system.

The baseline IRSS system includes the hardware and software components to provide a complete IR/EO simulation and test environment. Functionally, the IRSS system includes software to support off-line modeling, database development, scenario generation, and simulation control. Real-time functions include scene generation and sensor stimulation. The IRSS system supports both open-loop and closed-loop simulation. Open-loop simulation provides the user with the capability to execute predefined, time-sequenced scenarios ensuring total control over scenario events. Closed-loop simulation is supported through an external interface where the unit under test (UUT) and target position data can be generated by external simulations and provided to the IRSS system for reactive engagements

In an integrated configuration, the IRSS can be coupled with RF systems and facility-level composite mission simulators for correlated, synchronized multi-spectral testing. The IRSS supports the stimulation of single or multiple aperture sensor systems. The system is modular in design to support incremental expansion of both function and performance to meet current and future test requirements.

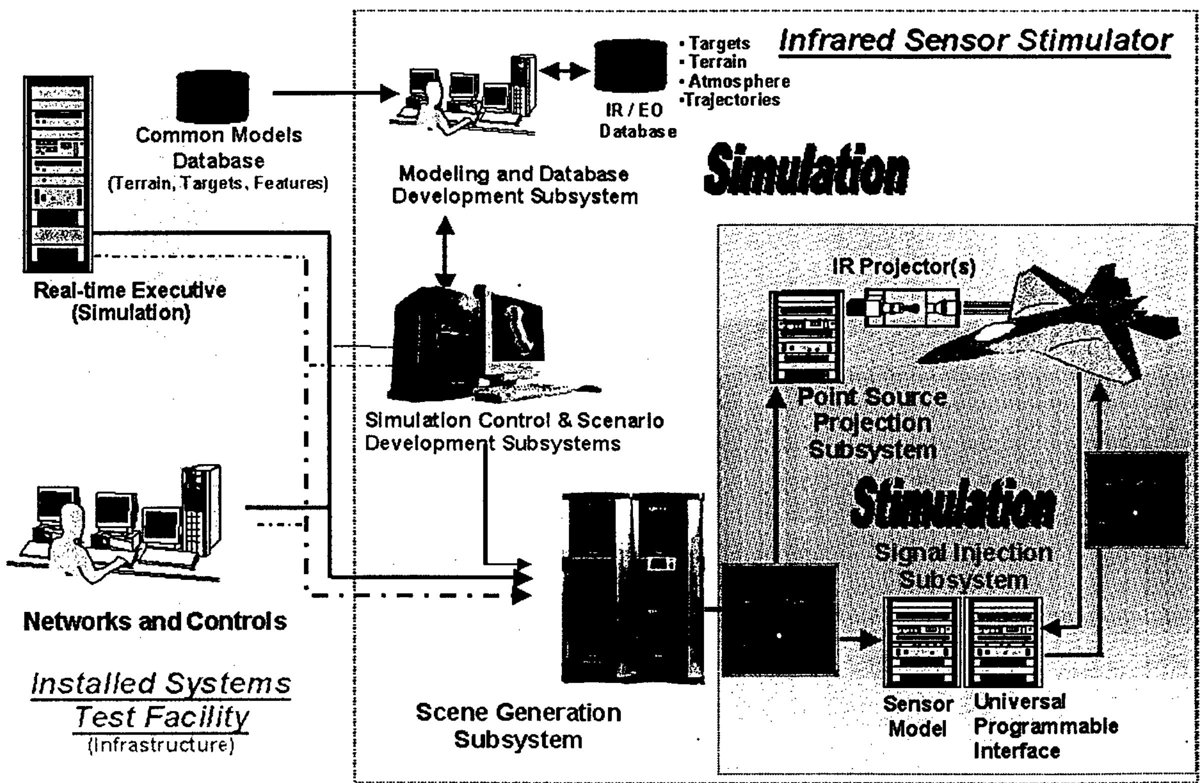

Figure 1 - IRSS System Architecture

IRSS SYSTEM ARCHITECTURE

IRSS is a family of integrated software applications and hardware that supports all phases of the IR simulation and test process. Applications are available for off-line modeling and scenario development, as well as real-time scene generation and sensor stimulation. The IRSS, as illustrated in figure 1, consists of six primary subsystems that are partitioned between off-line and real-time functions. The off-line functions include the Modeling and Database Subsystem (MDBS) and Scenario Development Subsystem (SDS). These applications provide the user with all of the tools necessary to model and construct a virtual T&E warfare environment including terrain, targets, false targets, and atmospheric/weather parameters. The Simulation Control Subsystem (SCS) and the Scene Generation

Subsystem (SGS) are the core of the system and provide the computing resources and processing required to generate infrared scenes in a real-time reactive mode. The two *stimulation* subsystems, the Signal Injection Subsystem (SIS) and the IR Point Source Projector (IRPSP) Subsystem, provide the capability for real-time electrical signal injection into the processing electronics and/or optical projection of scenes directly onto the sensor's detectors. COMPTEK-Amherst Systems Inc. (CASI) is developing the four subsystems of the scene generation/simulation component. CASI and SPARTA Inc. (SPARTA) are developing the SIS and IRPSP stimulation subsystems, respectively. A full field of view (FOV) image Scene Projection Subsystem (SPS) is planned as a future enhancement. UV generation and projection are also a planned future enhancement.

SCENE GENERATION CAPABILITY

The **Modeling and Database Subsystem (MDBS)** capability provides the test engineer/operator with the capability to build files representing threats, real and false targets, backgrounds, and atmospheric elements off-line. (e.g., In a non-real-time mode the operator will build files from sources such as plume radiance models, missile trajectory models, terrain elevation data, measured and/or statistically derived clutter data, and atmospheric models.) The primary output of the MDBS is the IR/EO Database, which contains the files used for subsequent scenario development and real-time simulation. The models identified in Table 1 are used in the calculation of signatures, atmospheric conditions, and target and test platform flight paths. Model selection is based upon degree of use in the simulation community, identified as a government "standard", e.g. endorsement by SURVIAC or JANNAF/CPIA, or some acceptable level of validation.

Model	**Function**	**Implementation**
Signatures		
SPF/SIRRM	Missile & Air Vehicle Plumes	Point source intensity only
SIRRM	Extended Plumes	Under investigation
SPIRITS	Air Vehicle Body	• 5,000 airframe facets typical • resolution → facet reduction • asynchronous, non-real-time execution via interface
PRISM	Ground Vehicles Ships	• 3,000-8,000 tank facets typical • resolution → facet reduction • asynchronous, non-real-time execution via interface
TERTEM	Terrain Heat Transfer/ Temperature	• MOSART/ERTEM terrain thermal is integrated • Black box interface for using other models
IRENE	Ships & Sea Backgrounds	• Ship signatures integrated as Openflight objects • Sea surface integrated as radiance textures
Atmospheric		
MODTRAN	IR Attenuation, Path Radiance & Solar Irradiance	• Real-time lookup tables from off-line execution • File based interface enables use of other models
OSIC	UV Background/Scattering	• Real-time lookup tables from off-line execution • Implemented as prototype only
Cloud	Background (not 3D)	Under investigation
Obscurant	Background (not 3D)	Under investigation
Trajectory		
BLUEMAX	Test & Adversary Air Vehicle Flight Paths	Integrated or off-line execution → scripted trajectory with interactive graphical way-point entry
ESAMS	S/A missile flyout	Integrated or off-line execution → scripted trajectory
TRAP	A/A missile flyout	Integrated or off-line execution → scripted trajectory

Table 1 – Third Party Model Utilization

The MDBS also supports importing and converting external database elements from common terrain or target databases that use a standardized open-architecture, three-dimensional geometric file format to provide commonality with other ISTF stimulators. Extended OpenFlight™ has been selected as the "standard" for model input/output and databases. The IRSS incorporates the MultiGen™ Application Program Interface (API) as a tool to support the creation, attribution, integration and execution of the models and databases. Use of the MultiGen™ also enables the import and manual attribution of other external databases. This process is illustrated schematically below using extended targets as an example.

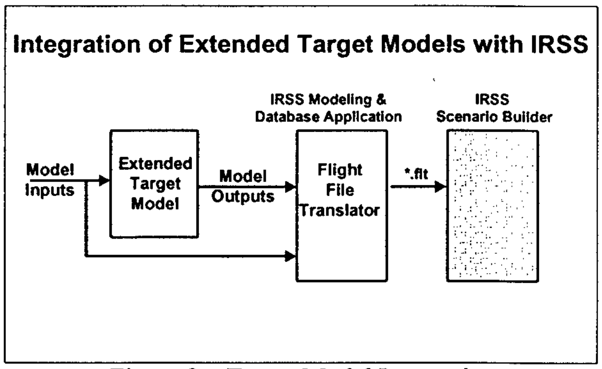

Figure 2 – Target Model Integration

The construction of a Flight File Translator (FFT) is performed once for each external model that is to be used by the system. The primary objective of the FFT is to transform the model's native geometry representation into the OpenFlight™ format. The secondary objective of the FFT is to automatically place the appropriate object temperature and material attributes into the OpenFlight™ file. After this process is completed, the resulting OpenFlight™ files can be accessed and specified as scenario components through the IRSS Scenario Builder application. In the past year this process has been used to successfully import and utilize the outputs of PRISM, SPIRITS, and IRENE in IRSS scenarios.

The output of the FFT is an OpenFlight file representative of the conditions for which the external model was executed. There are instances where some of the original conditions will change during the course of a scenario. Examples include tank barrel heating, engine compartment temperature, and throttle setting. These changes can be dynamically incorporated into a scenario through the Plug-In-Interface. This interface provides a mechanism by which specific changes can be incorporated into an object description when executing a scenario in real-time. The Plug-In interface is non-synchronized interface that enables 3rd party or other external models to provide asynchronous updates to executing scenario files. The update frequency depends on model performance and the fidelity required for the target, and/or background signatures.

Model translators are interfaces to MDBS. They can be developed by Comptek Amherst Systems, Inc. or by IRSS users. Each model translator can consist of a graphical user interface, a model processing function, and database translator. The graphic user interface (GUI) provides easy and efficient execution of the model. This feature is important when operators are unfamiliar with the specifics of each model. The model processing function compiles the model output and performs the necessary manipulation of data for real-time scene generation. The database translator formats the data into a common database format for scenario development and scene generation.

The Modeling and Database Subsystem contains the models, tools and databases used to represent targets and backgrounds in the test scenario.

To compensate for their non-real-time execution speed, some models, e.g. MODTRAN, ESAMS, TRAP, are executed off-line to create look-up tables or databases that are used during run-time scene generation. Once created, these look-up table databases become part of an EO/IR library. The IRSS System is required to respond to unscheduled, non-scripted events including man-in-the-loop commands in the external control-state whereas the trajectory models within the IRSS System are only intended for scripted applications. Not all of the models are restricted to off-line execution.

The **Scenario Development Subsystem (SDS)** provides the operator/test engineer with the capability to define simulation scenarios in which single or multi-sensor equipped vehicles moves through a virtual/simulated test area. The output of the SDS is a scenario file that is saved in the scenario database. The scenario file references scripted terrain, targets, threats, trajectories and special effects selected from the IR/EO Database. The file also references customized simulation elements. These elements include an atmospheric specification, sensor specification, test platform assignment, sensor channel assignment(s), and state information such as situation display setup, visual display setup, and instrumentation setup. The SDS provides a convenient user interface for quickly building or editing scenarios based on libraries of objects created in the MDBS. An interactive situation display provides a graphical scenario building and display capability. The situation display features interactive control of viewing geometry, symbology, and scenario components. An interactive scenario sequencer provides the ability to setup scenario parameters and script scenario events. Used in conjunction with the situation display, the sequencer provides an efficient environment for building, editing, and previewing test scenarios. The IR models TRAP (Trajectory Analysis Program), BLUEMAX (Aircraft trajectory), and ESAMS (Enhanced Surface-to-Air Missile Simulation) have recently been integrated with the SDS. As a result of this integration, the situation display now includes a scenario sequencer that can be used to provide an interactive graphics based environment for the preparation of scripted trajectories. During the scenario development process, the scenario can be previewed using the scenario animator. This feature allows the operator to pre-run the test engagement and evaluate scenario events against the simulation timeline. The scenario gaming area, player motion, and unit under test FOV are visualized in the situation display. Simulation clock controls are provided to stop, start, and pause the scenario.

The **Simulation Control Subsystem (SCS)** provides the operator/test engineer with the capability to control the execution of a simulation and perform fault tests on the IRSS channel hardware. A fault test and diagnostics capability is provided for assessing the health of the system and to assist in the operational maintenance of system components. Input to the fault test function includes diagnostic scripts executed by the operator to determine the hardware operational state. Output consists of the pass/fail status of the performed tests along with status or trace messages showing test progress. Upon execution of the IRSS application, the SCS initializes by opening an existing or archived simulation file from the scenario database and setting the control-state. When external/integrated control is disabled, the IRSS operates in a stand-alone mode in which the operator controls the simulation clock, the situation display, the visual display, and all instrumentation. When external control is enabled, control of the simulation clock, player positions and state, test platform interface, etc., is assumed by the ISTF Operational Control Center (OCC). The OCC may send a Load/Initialize command to the SCS that contains a scenario script specifying some or all scenario and configuration information.

The **Scene Generation Subsystem (SGS)** produces IR/EO scenes in real-time. The term "real-time" is relative to the frame rate of the sensor under test (e.g. 30 – 100 Hz for FLIR, 100 – 400 Hz for MWS). The SGS incorporates "first principle" algorithms for the radiometric signature computation. A "virtual" test may involve stimulation of up to three sensors requiring multiple SGS channels. Each channel stimulates a single sensor or a single aperture of a multi-aperture sensor. A sensor-specific configuration is supplied during initialization. The SGS performs both scene generation and scene rendering. During scene generation, the SGS determines the test scenario viewed gaming area, on a frame to frame basis, based on the direction/view of the sensor line-of-sight, and host platform position in space (e.g. altitude, heading, pitch, roll). The specified simulation file is examined to determine which polygons, representing players/targets and background elements, occur within the viewed area, and are to be displayed in the simulation. The material characteristics and polygon viewing geometry are used to calculate radiometric values for polygon vertices. During scene rendering, polygons are decomposed into pixel elements and inserted into an output frame buffer resulting in a radiometric, spatial, and temporal representation of the scene as viewed by the sensor relative to its line-of-sight. This digital scene is the input from the SGS into either the SIS, for conversion into an electrical signal that is injected into the sensor processing electronics, or the IRPSP, for optical projection into the sensor's entrance aperture. Additional discussion of this subsystem is presented below.

The **IRSS Scene Generator** generates radiometrically accurate scenes for installed systems testing of a wide variety of infrared and ultra-violet sensor systems. The generated scenes provide a realistic portrayal of the in-band scene radiance as viewed by the system under test in operational scenarios. Scene radiance is calculated on a frame by frame basis accounting for the relevant contributions from the sky, sun, targets, terrain, and atmosphere as a function of the engagement geometry. The frame output of the scene generator is configurable to match the characteristics of the sensor system under test. Sensor parameters such as frame size, frame rate, spectral band, number of bands, pixel resolution, and field of view are user configurable. The digital output can be formatted for direct injection into receiver/processor hardware or to drive an infrared projection system.

The IRSS Scene Generator was designed specifically to address the core technical issues for IR/EO scene generation. Commercial scene generation systems are optimized for visual effects and standard display devices. Real-time IR/EO sensor stimulation requires a higher level of fidelity (scene quality and radiometric content) and usually involves large frame sizes at high frame rates. The current Scene Generator hardware configuration consists of a Silicon Graphics Onyx2 InfiniteReality® graphics computer with eight or twelve "R10000" processors. The system can use either the SGI InfiniteReality® or the COMPTEK-Amherst Systems Scene Rendering Subsystem (SRS) for final image rendering. The SRS is designed specifically for infrared applications while the InfiniteReality® is optimized for visual applications. The selection of the graphics system depends on the objective of the test facility. When evaluating the detection, tracking, or guidance performance of a sensor system, fidelity and radiometric validity are critical. In this situation, the accuracy and programmability of the SRS may be required. In cases where radiometric accuracy is less important and validation is not an issue, the InfiniteReality option may be preferred.

The **IRSS Scene Rendering Subsystem** (SRS) is a graphics processing pipeline developed specifically for rendering IR/EO scenes. The SRS overcomes many of the problems associated with adapting visual rendering systems for IR/EO simulation. The SRS uses full 32 bit floating point accuracy for all calculations including radiance (lighting), transparency, texture mapping and filtering, anti-aliasing, and hidden surface removal (z-buffering). The SRS can process up to six 16 bit colors or three 32 bit colors per pixel. Equations for pixel level lighting and atmosphere effects can be modified as desired to make tradeoffs between rendering accuracy and speed. Depending on the tradeoffs selected, a fully configured SRS can provide more than four times the radiometric accuracy of the Silicon Graphics InfiniteReality®. In addition, the SRS can be tightly coupled with an IR/EO sensor in a reactive closed loop configuration, and dynamic frame size and frame rate changes can be processed with low latency

SCENE PRESENTATION CAPABILITY

The **Signal Injection Subsystem (SIS)** accepts digital scenes produced by the SGS and creates an electrical digital or analog signal that is injected into the sensor image/signal processing chain. This subsystem is currently being developed and will be manufactured by COMPTEK-Amherst as a deliverable under an Air Force SBIR contract for a Universal Programmable Interface (UPI).

As part of the signal creation function, the SIS must modify the scene to represent the effects of by-passed sensor components/phenomenology prior to the injection point, convert the modified image to a properly conditioned electrical signal, and provide the electrical connection to the sensor. The scene modification is accomplished by two custom processing components within the SIS, a convolution processor and a pixel processor. These SIS components use digital signal processor (DSP) arrays; high-speed Xilinx programmable gate array chips for the convolution processor, and Motorola 266 MHz Power PC 740 chips for the pixel processor. The latter hardware assembly is common to the polygon processor in the previously discussed COMPTEK-Amherst rendering engine. The Sensor Interface Module (SIM), which is unique to each sensor, provides generation and conditioning of the electrical signal and its physical connection to the sensor. This assembly is a plug-in module that enables the SIS to be easily configured for different sensors.

Additional functions of the SIS include processing (e.g. I/O handling) sensor control signals and, if necessary, emulating their functionality. These functions may require one or more electrical connections to the sensor or other test platform avionics systems. The SIS is based on the COMPTEK-Amherst Systems Universal Programmable Interface (UPI) which is discussed in more detail later in this paper.

The **IR Point Source Projector (IRPSP)** is another stimulator sub-subsystem that presents a generated scene to the sensor. The primary function of the IRPSP is to accept digital input scenes produced by the SGS and to generate equivalent output scenes, in the form of in-band electro-optical/infrared energy, for projection into the entrance aperture of the Unit Under Test (UUT). The format of the scene input to the IRPSP from the SGS will be Silicon Graphics, Inc. (SGI) Direct Digital Output for the Onyx2 (DDO2), also known as the Onyx2 Digital Video Port (DVP). The IRPSP will also be capable of receiving scene input from the SIS in a DDO2 format. Setup and control of the IRPSP will be managed by the SCS via the SGS to IRPSP interface. The IRPSP will consist of seven primary subsystems. These subsystems are the Control Electronics Subsystem (CES), Environment Control Subsystem (ECS), Infrared Emitter Subsystem (IRES), Mounting Platform Subsystem (MPS), Non-Uniformity Correction Subsystem (NUCS), Projection Optics Subsystem (POS), and Software Control Subsystem (SCS).

NEW CAPABILITIES

Advances in Maritime Modeling

A requirement for IRSS to test the US Navy's AAS-44V FLIR system led to the introduction of a Maritime Combat Environment (MACE) modeling capability into IRSS. This involved the integration of a maritime thermal model derived from the US Navy's IRENE model.

The fact that the integration of this model was a smooth process is due to two main factors; cooperation between the developers of IRENE and Comptek Amherst Systems and the easily accessible OpenFlight format used by IRSS. The cooperation between the two parties allowed the work to be done in a minimal amount of time. Also, the expertise of the US Navy development team allowed for great control of the way in which IRENE could be used for implementation. The Application Programmable Interface (API) component of the MultiGen-Paradigm's *Creator* program enables easy access to the OpenFlight format. Consequently, conversion of the IRENE file format to the IRSS-supported OpenFlight format was very straightforward.

A major portion of the MACE effort involved the development of a method for the creation and rendering of the ocean background. The background is generated by a ray-tracing routine based on The Naval Research Laboratory's KELSEA model, which computes the source radiance of each square texel in a 512 x 512 grid. These texels can have a size of 1m or 5m on an edge, resulting in higher or lower resolution-radiance map textures. These radiance maps are then rendered by IRSS, which computes the atmospheric effects.

The MACE team is currently seeking to identify sources of future funding for the continued development of the MACE capability. Some of the features earmarked for future work include the rendering of wakes, the creation of sea height maps for ocean backgrounds and the inclusion of plumes in ship models. Figure 3 is a sample maritime image generated by IRSS.

Advances in Terrain Simulation

Terrain definitions are fully attributed, faceted surface descriptions derived from Digital Terrain Elevation Data (DTED) augmented with cultural details such as roads, bridges, and buildings. The DTED data is used to create polygonal wire-frames representing terrain contour or shape. Terrain attributions include material properties, textures, and temperature specifications. Background detail (e.g., texture) at the sensor pixel level is represented by texture maps overlaid on larger terrain polygons.

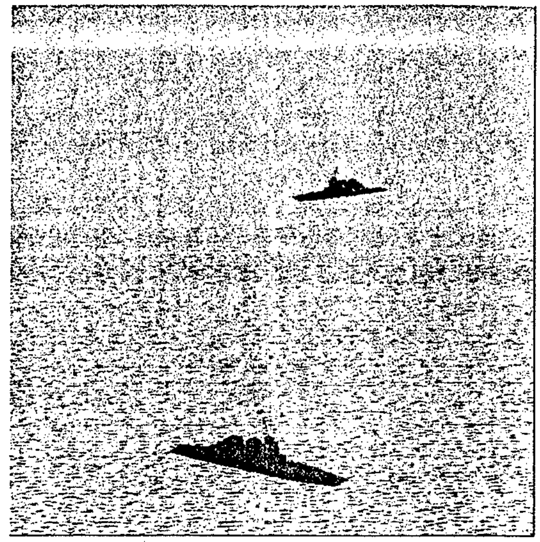

Figure 3 – Example Maritime Scene

(The ocean surface texture is 1m resolution and a sea state of 2. The sensor altitude is ~1400m with a look angle of −10°. Ranges to the two ships are 740m and 1560m. White is hot.)

Radiometrically-correct real-time simulation of realistic terrain requires three essential elements. First, a high-resolution description of the physical properties of the terrain, both in terms of material composition and topography is needed. Second, high-fidelity models for the sensor and its physical environment must be employed. Finally, sophisticated algorithms must be employed to combine the models and the terrain description into rendered scenes accurately and in real-time.

IRSS effectively combines these three elements, providing a new level of realism to real-time sensor simulation. Since the terrain description is based only on its physical properties, it can be used to simulate the terrain regardless of the waveband(s) of the sensor being modeled, and correlation of different waveband images is easily accomplished. The description can also be used in conjunction with a thermal model to include realistic seasonal and diurnal effects. Radiometric accuracy is achieved through the use of accepted phenomenological models and advanced algorithms. Geo-specific texturing results when correlated satellite imagery and digital elevation models for a specific region are used to create the terrain description.

Terrain Description and the Models

Increased availability of satellite imagery, and the development of sophisticated image analysis techniques, has made the high-resolution description of terrain material composition a practical reality. Classification techniques are employed to determine the material or material mix of the terrain from satellite images on a texel-by-texel basis. A material code number is assigned to each texel, and all the codes for a specific patch of terrain are assembled into a "material map", or, in the case of a material *mixture* being assigned to a texel, a "material mix map". The material codes are cross-referenced to a table that gives the pertinent properties of each material. The use of material mixtures has an advantage over using a single material per texel in that it enhances the level of detail in the terrain image and smoothes the transitions between regions of differing material types.

Two types of topographic descriptions of the terrain are required. First, the effective utilization of computer graphics technology drives the need for the terrain to be described in terms of a triangular irregular network, or TIN. A TIN representation is readily obtained from government-distributed digital elevation data by using commercially available Delaunay algorithms.

The second type of topographic description required is at a higher, texel-level, resolution. This is necessary due to the sensitivity of the texel's radiance to its normal vector and its elevation. While the texel's source radiance is modeled as being independent of its orientation (i.e., Lambertian), its normal vector and elevation can have a significant impact on the source radiance, by effecting the texel temperature. The normal vector also determines how much sunshine, skyshine, and earthshine the texel reflects. The texel-level topographic data is readily derived from digital elevation data using standard interpolation and gradient estimation techniques.

To efficiently store texel-level terrain data a new file format, called MMT (for material mix and topography), was developed for IRSS. This format stores the material mix data for each texel, as well as the texel-level topographic data, into a single file, which is then correlated to a TIN in the same manner as a normal texture. The topographic data takes the form of elevation, 2-D gradient, and cross-derivative samples at equally spaced posts. Elevation and normal vector data is then easily calculated at intermediate texel locations using bi-cubic interpolation. This bi-cubic representation itself reduces the storage requirement from 16 bytes/texel to less than about 1 byte/texel. The post spacing is selected to approximate the resolution of the source data, which can result in further efficiency without adding any additional processing burden.

The primary models employed by IRSS in terrain simulation are for sensor spectral response, atmospheric effects, and for the determination of terrain temperatures. The user models the sensor spectral response during the scenario development process by simply entering sensor response values, and corresponding wavelengths, into a table. Atmospheric effects are modeled using the industry-standard atmosphere model, MODTRAN (Moderate Resolution Transmission). The IRSS architecture is designed to facilitate the use of different thermal models, but currently uses only TERTEM.

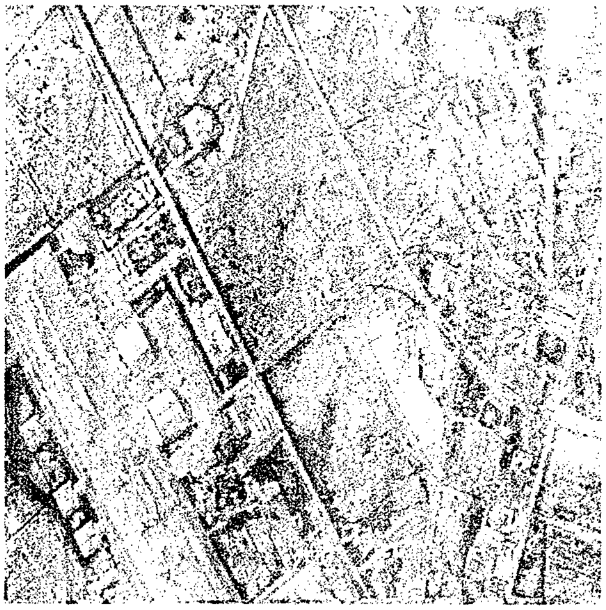

Figure 4 – Radiance Map Terrain

Terrain Rendering Algorithms

For maximum efficiency, the terrain rendering algorithms are carefully designed to perform optimized pre-run-time calculation while also preserving accuracy. This non-real-time calculation consists of the generation of lookup tables and texture. The lookup tables are used to calculate attributes for terrain facet vertices that vary widely with the position of the sensor relative to points on the terrain. These attributes account for the effects of atmospheric attenuation and path radiance. The texture is used to account for a number of first principles physical effects including temperature variations, thermal radiation, and solar, skyshine and earthshine reflections. The generation of this texture, called an adjusted radiance map, is expedited by first generating, and then using, lookup tables.

Once the lookup tables, and adjusted radiance map, are pre-calculated, the real-time portion of the simulation can begin. The attributes of terrain facets within the field-of-view are calculated on a vertex-by-vertex basis, and the results sent to a rendering engine along with the specially-formulated texture. The IRSS has the capability to render scenes using either SGI graphics hardware, such as the InfiniteReality, or by using CAS's SRS, which is designed specifically for sensor applications. In either case, a unique rendering algorithm is employed to create the desired imagery with high accuracy.

To assess the accuracy of this new rendering technique, precise calculations of the apparent radiance of the terrain were compared to the results that would be obtained using the rendering technique, for a wide variety of sensor-to-terrain geometries and parameter variations. This showed that the error introduced by the algorithms used were generally a fraction of a percent, but that in certain extreme cases can grow to approximately 1%.

A Universal Programmable Interface (UPI) has been developed under the IRSS program to provide such functionality. Unlike custom solutions, the UPI provides a reconfigurable method for interfacing a wide range of UUTs through either direct injection or optical projection. This flexible capability is achieved through the use of a core architecture that provides industry standard interfaces, coupled with minimal custom interface hardware and reconfigurable software. The UPI provides the physical interface between an SGS and the UUT, performs sensor modeling, and emulates missing components. An illustration of using the UPI in hardware-in-the-loop (HWIL) sensor system testing is shown in Figure 5.

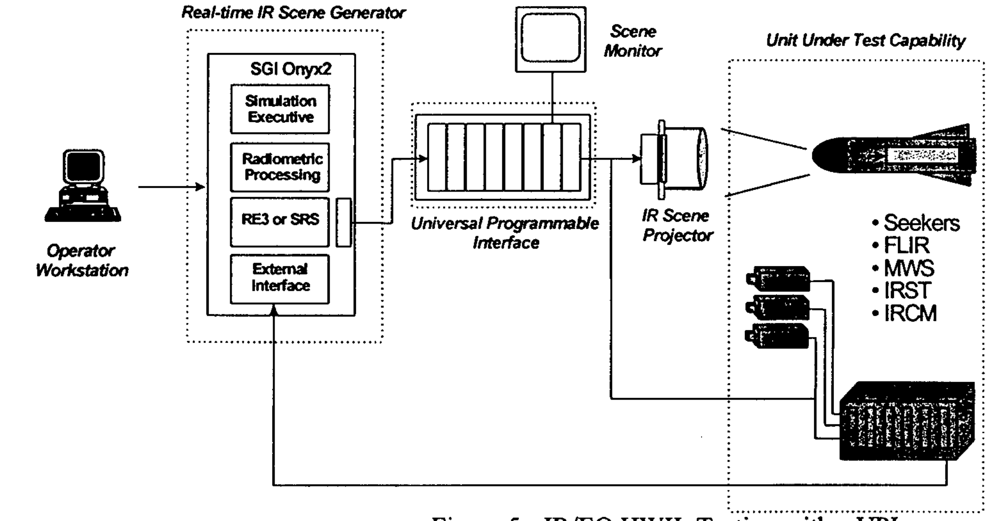

Figure 5 - IR/EO HWIL Testing with a UPI

Advances in Sensor Simulation

IR/EO sensor system testing requires valid stimulation of the UUT to correctly determine the performance of the sensor system and processing algorithms. Assuming the scene generation system (SGS) has correctly modeled the target/background signature and atmospheric attenuation, other requirements exist for valid stimulation. A physical interface is required between the SGS and the UUT to properly reformat the data such that it can be introduced to the UUT either through the direct injection of the signals into the system's processing electronics or the projection of in-band scene radiance into the sensor's optical aperture. By-passed missing components such as gyros and gimbals must be emulated. Real-time sensor modeling must be performed to correctly model the by-passed sensor optics and electronics for the case of direct signal injection. Additionally, optical projection requires non-uniformity correction (NUC) of the thermal array.

Both current and notional sensors can be modeled with the UPI, providing system designers the capability to measure the effect on performance due to changes in sensor design. Additionally, the UPI can be used in applications requiring high speed general purpose image processing capabilities.

The top-level architecture of the UPI is illustrated in Figure 6.

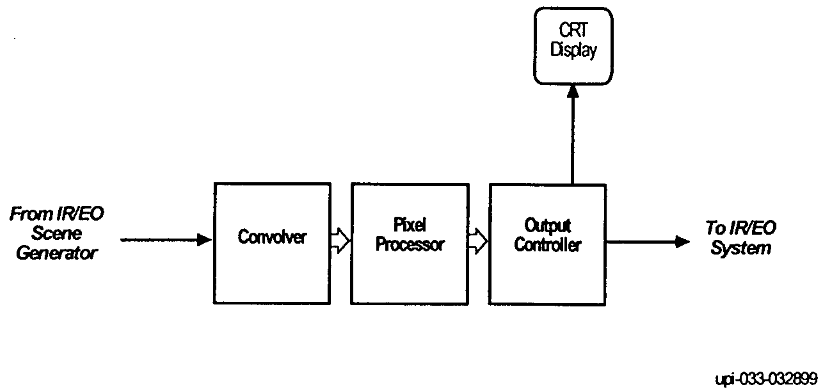

Figure 6 - UPI Top-level Architecture

Convolver

For direct signal injection, the UPI must accurately model the modulation transfer function (MTF) effects of the by-passed sensor optics and electronics. The MTF is modeled through the convolution of a spatial kernel in the convolution subsystem (convolver). This kernel is generated off-line through the use of the UPI sensor modeling software developed at Comptek Amherst Systems (CAS). FLIR92, an industry standard tool for IR sensor characterization and performance modeling, was chosen as a basis for this software. Based on the input sensor parameters, this tool provides the user with the ability to generate the convolution kernels that model the sensor MTF. The user can model the MTF of current and future sensors

In the convolution subsystem, the over-sampled rendered scene is convolved with the MTF kernel, producing the image as seen by the sensor. Ideally, a static mapping between the sensor pixels and the scene pixels would exist. However, multiple factors can contribute to sensor pixel displacement from the perfectly rendered image to the correctly sensed image, including scene rendering latency, optics induced geometric distortion, and physical sensor jitter. In addition to convolution, the convolution subsystem handles these factors through displacement processing.

In a closed loop installed systems test configuration, latency can occur between the time when positional data is received and when the scene is rendered. Latency can create errors in x and y shift, and in rotation, which can consequently affect the ability to accurately test the system under test (SUT). This is a problem for both direct signal injection and projection. Therefore, the UPI performs latency compensation to extract the correctly located sensor image from within the oversized scene image.

Within a real sensor, the optics generate geometric distortions in the sensed scene. Edges that are geometrically straight appear curved which is an effect that is especially pronounced with wide field-of-view optics. Accurate emulation of the optics-induced distortion may be required when performing direct signal injection since the optics are by-passed. If the SGS does not perform the geometric distortion, then the compensation can be performed by the UPI as an additional sensor effect modeled by the system.

Sensors can experience physical jitter when mounted on a moving platform. For a scanning system, this could create small perturbations in the location of each successive scan line. If jitter affects the system performance, it should be accurately modeled. Assuming the jitter function can be mathematically modeled, it too can be handled by the UPI. Additionally, a variety of other user-defined mathematical displacement effects can be modeled.

Pixel Processor

A variety of noise sources and response non-linearity's that are present in sensors can affect performance. When performing direct signal injection, the sensor is by-passed. Therefore, these pixel effects are modeled, based on user specified sensor parameters, in the pixel processor to add to the validity of the installed systems test.

Some of the pixel effects that have been modeled include conversion from radiance to photons, various noise sources, linear responsiveness and automatic gain control (AGC).

The pixel processor utilizes a commercial off the shelf (COTS) circuit card assembly that contains general purpose processors. This board was originally designed for and used in the Amherst SRS. Since the pixel effects are implemented as software executing on the general-purpose processors in the pixel processor, a wide variety of effects can be modeled in the UPI. User-defined effects, within the limits of the UPI, can easily be added with no change or cost in hardware.

Optical projection can also benefit from the pixel processor. Gain and offset tables can be loaded in the resident memory and used for NUC.

CONCLUSIONS

The IRSS is a cost-effective system that provides flexible, re-configurable, reproducible and repeatable full test environments for evaluating IR/EO sensor systems during the concept, research, development, prototype, and test and evaluation phases. When employed as an integrated ISTF element, it is a valid / verifiable test and evaluation risk reduction tool that optimizes use of costly range testing. The IRSS sensor modeling capability contributes to the development of systems and sensor, and engineering model development (EMD) performance effectiveness evaluation.

The scene generation component has successfully completed its Spiral 4 development and the software has been delivered to the Navy and Air Force for evaluation. The signal injection component has completed PDR, and the infrared point source projection component has completed the critical design review for both systems. Final IRSS/facility integration is scheduled for 3rd. Quarter Government Fiscal Year (GFY) 2000, and will occur at the Air Combat Environment Test and Evaluation Facility (ACETEF), NAWC-AD, Patuxent River, MD and the Avionics Test and Integration Complex (ATIC), AFFTC, Edwards AFB, CA.. The system's Fully Operational Capability (FOC) completion is scheduled for the fourth quarter of GFY 2000.

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